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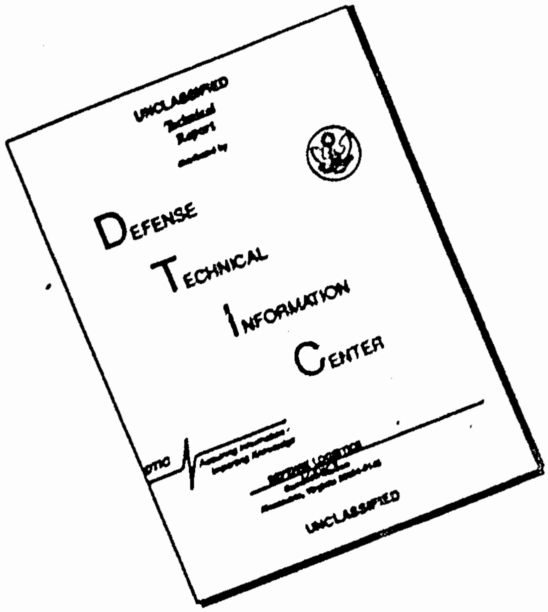

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FINAL ENGINEERING REPORT

ANGLE OF SITE

FEASIBILITY STUDY

61-4-3

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A

BELOCK INSTRUMENT CORPORATION
FINAL ENGINEERING REPORT

ANGLE OF SITE FEASIBILITY STUDY

CONTRACT NO.

DA-30-069-ORD-3114

SALES ORDER NO.

14434

August 1961

Approved by: S/

Checked by: S/

Prepared by: S/

PORTIONS OF THIS DOCUMENT WERE
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I INTRODUCTION

This is the final engineering report of the Angle of Site Feasibility Study. Most of the conclusions and recommendations were pointed out in the interim report of January 1961 (a copy of which is attached). This final engineering report will augment the conclusions and recommendations contained in the interim report.

II CONCLUSIONS

A. Correction for the error due to neglect of angle of site is feasible, and a correction equation can be formulated to accommodate most ammunitions.

B. Instrumentation of this correction can be made simply and for a comparatively small cost.

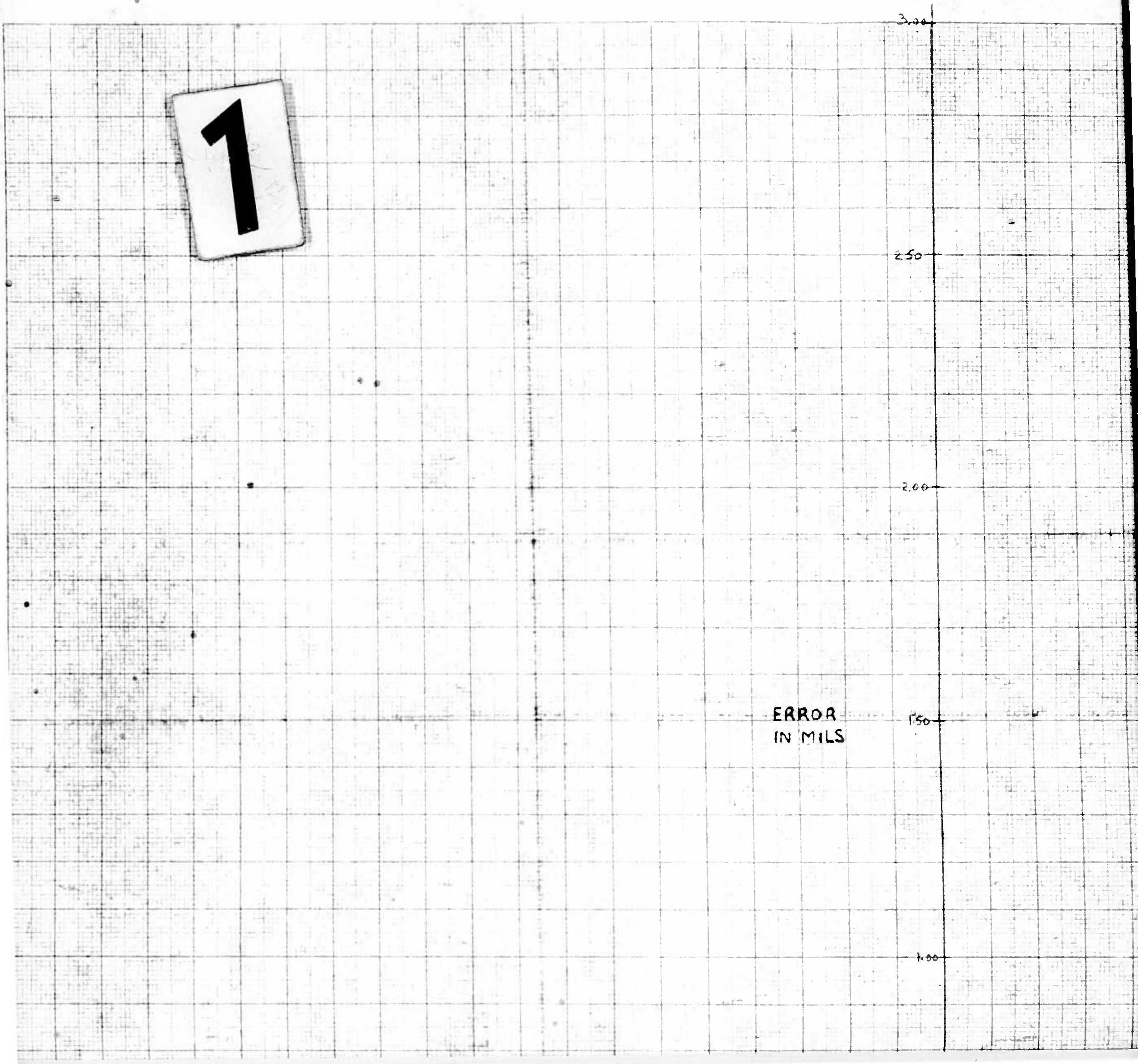
C. Inasmuch as the XM16 Computer was designed to perform with an overall accuracy 0.2 mil, optimum operation can never be attained unless some correction is made for the angle of site error. By comparing figure 1 to figure 2, it is shown that the error is reduced by a factor of greater than 10. The maximum error remaining after correction is seen to be 0.18 mil as compared to an error of greater than 2.0 mils without correction.

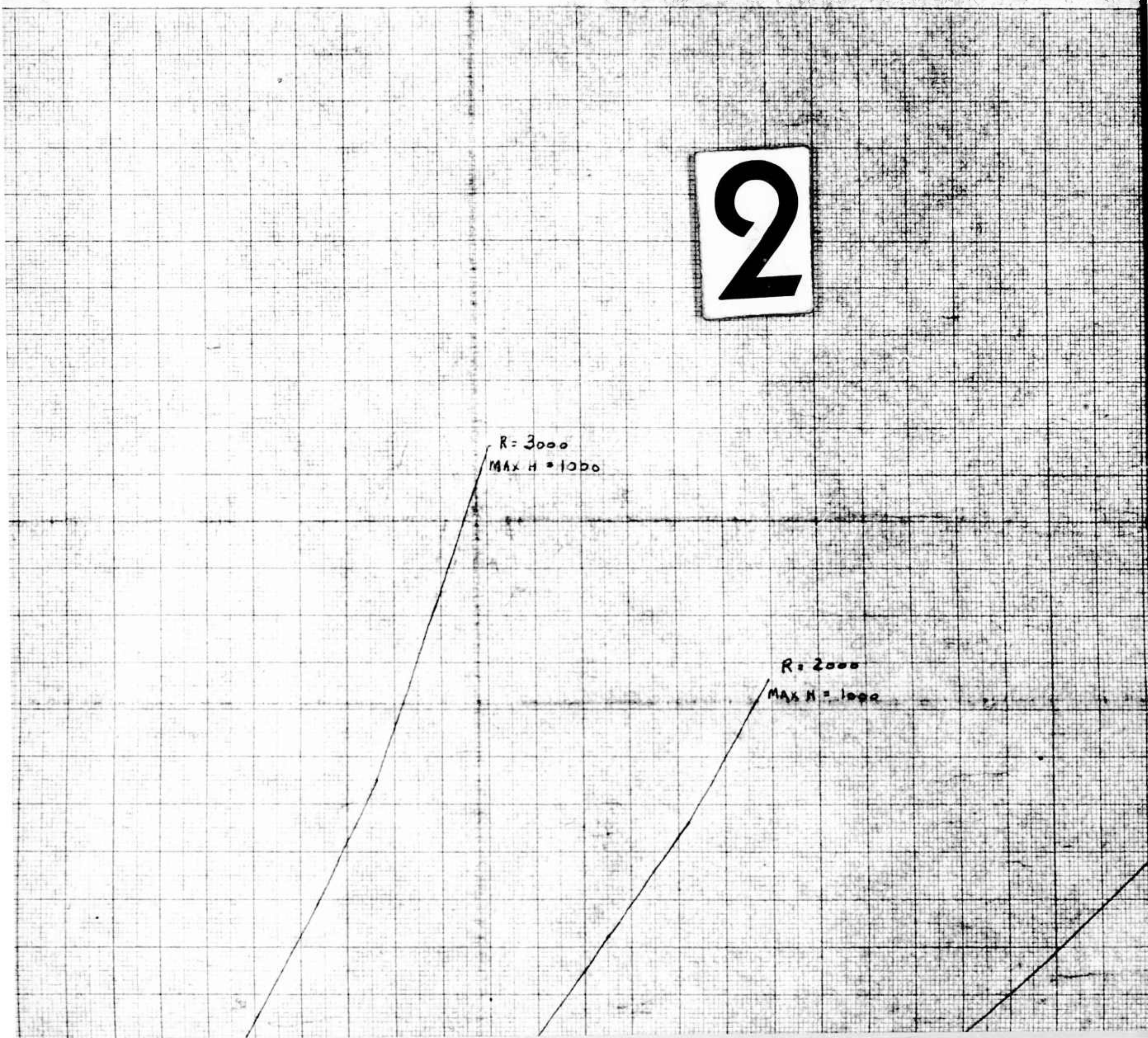
Referring to figure 2, the error has actually been overcorrected. This is a function of the constant "K" term in the correction equation. At the time this particular "K" term was chosen, the 4000-yard errors were being considered for correction as well as the 1000-, 2000-, and 3000-yard range errors. Since the 4000-yard range is beyond the area of interest and is to be disregarded, a new "K" term could be chosen which would further minimize the remaining errors after correction for the three ranges concerned.

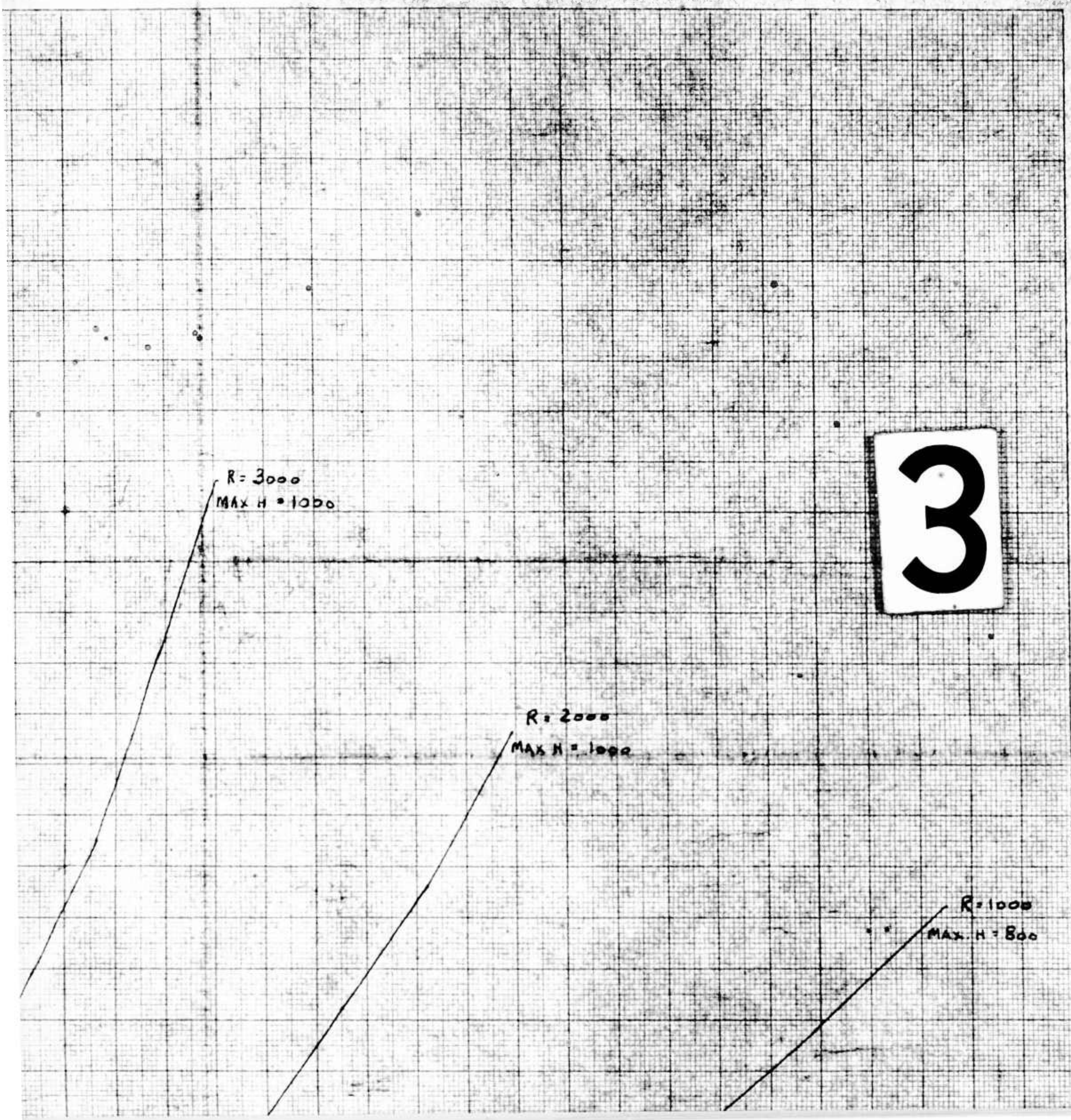
III RECOMMENDATIONS

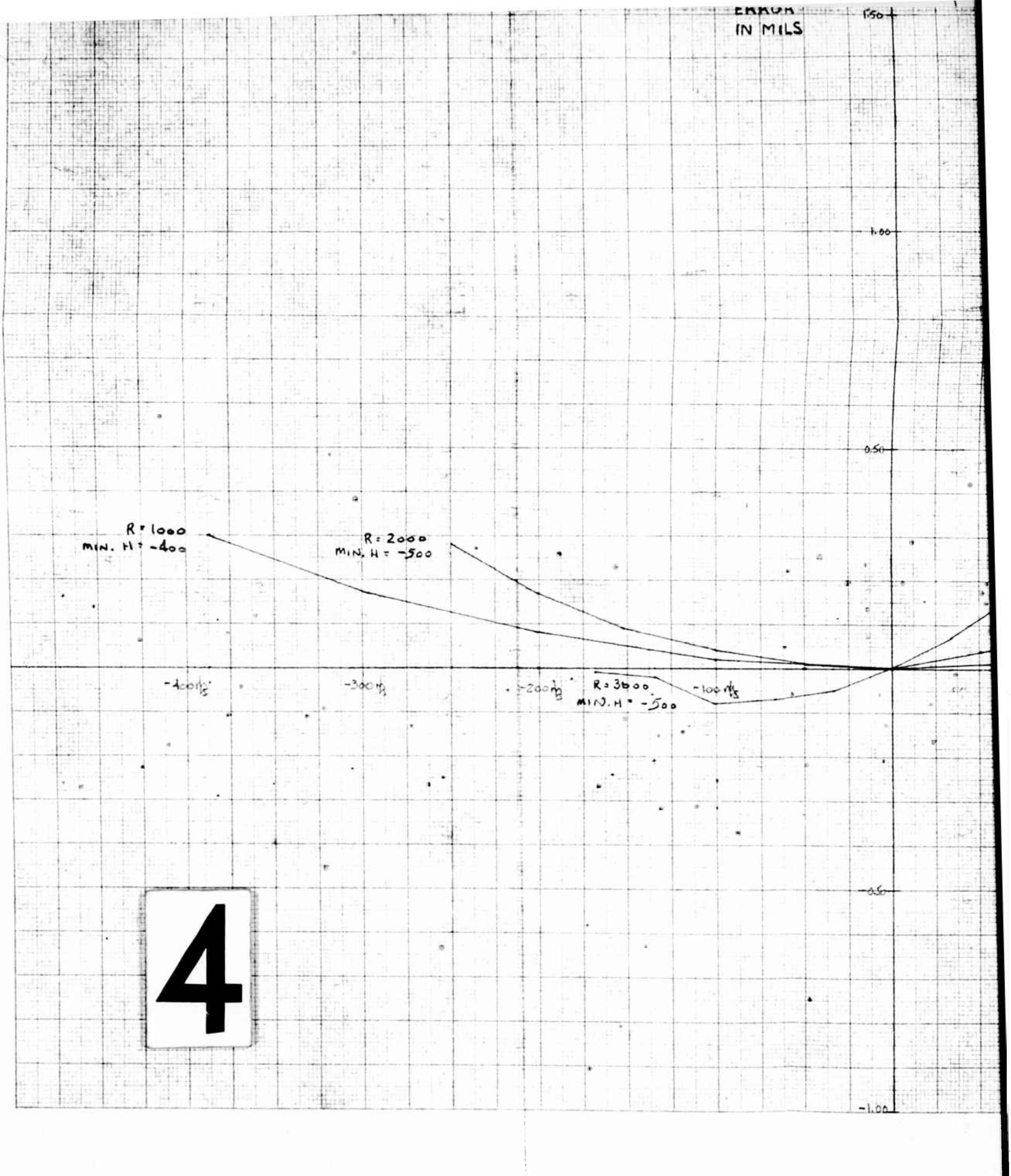
A. The correction equation described in the interim report and referred to in the conclusions of this report applies directly to the two ammunitions studied, HEAT-T-300 and APDS-T-392. A request for additional funds has been made and is recommended now in order that additional ammunitions may be studied. A family of ballistic curves could be generated, and from this data the present correction equation could be modified so as to be applicable to all ammunitions involved.

B. It is further recommended that a simple pendulous device, which would generate this correction, be designed and built for mechanization into the computer.


1
3.00
2.50
2.00
ERROR
IN MILS
1.50
1.00


2
R = 3000
MAX H = 1000
R = 2000
MAX H = 1000


R = 3000
MAX H = 1000
R = 2000
MAX H = 1000
R = 1000
MAX. H = 800
3



ERROR
IN MILS
1.50
1.00
0.50
-0.50
-1.00
R = 1000
MIN. H = -400
R = 2000
MIN. H = -500
R = 3000
MIN. H = -500
-400 mils
-300 mils
-200 mils
-100 mils

4

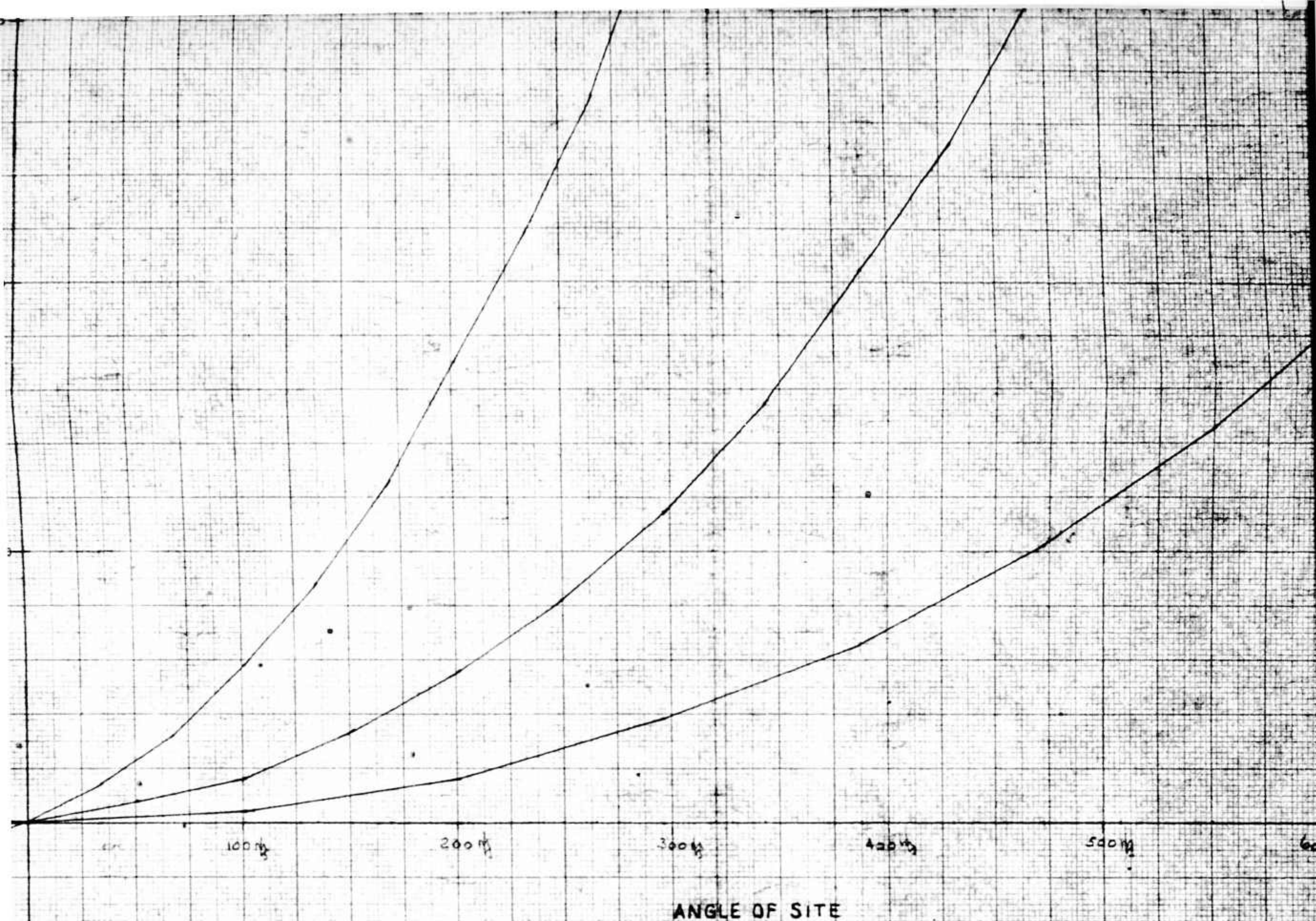


FIGURE 1

RANGE & H

UNCORRECT
NEGLECT C

14434

5

FINAL ENG. REPORT
CONTRACT # DA-30-069-ORD-3114

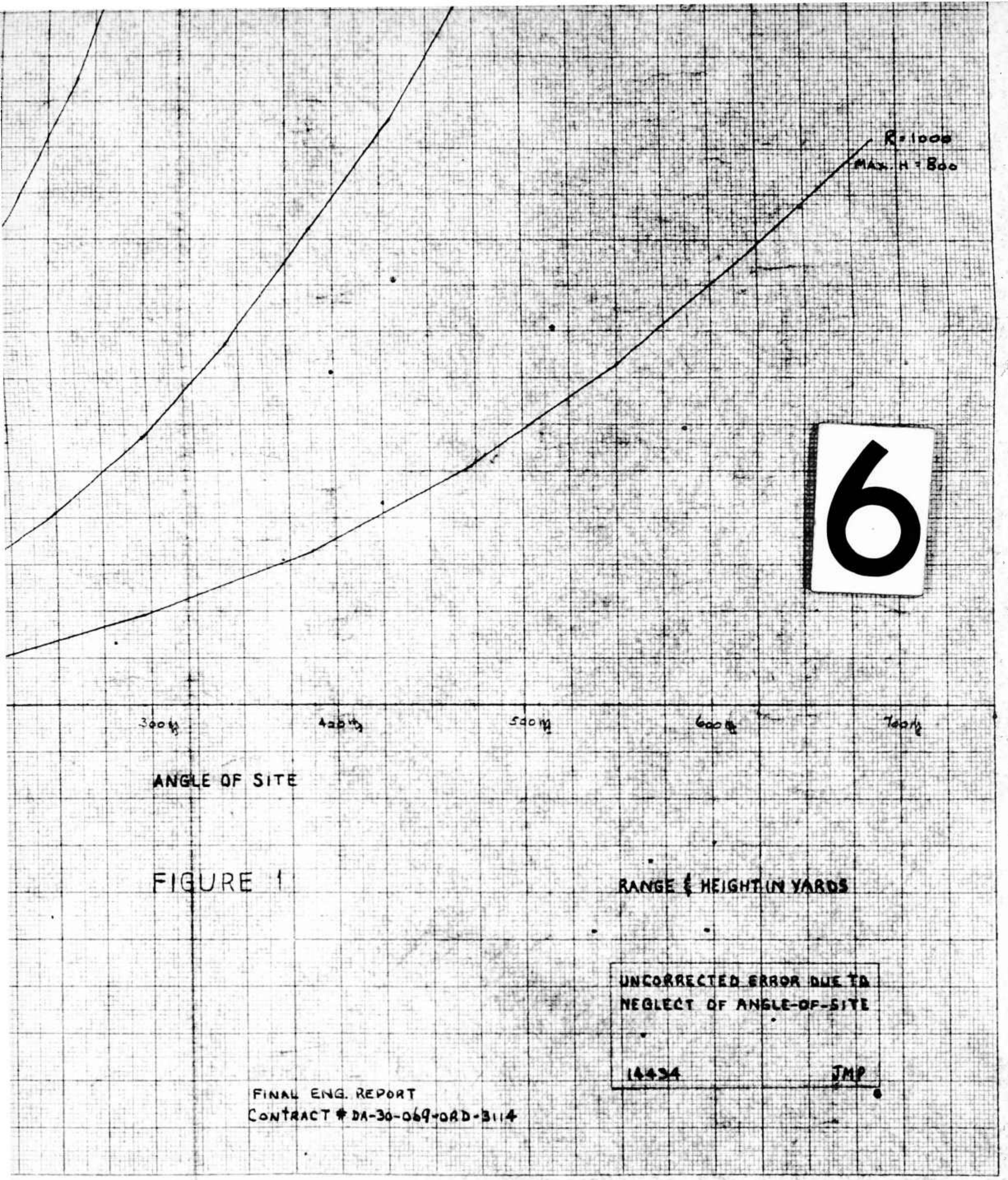
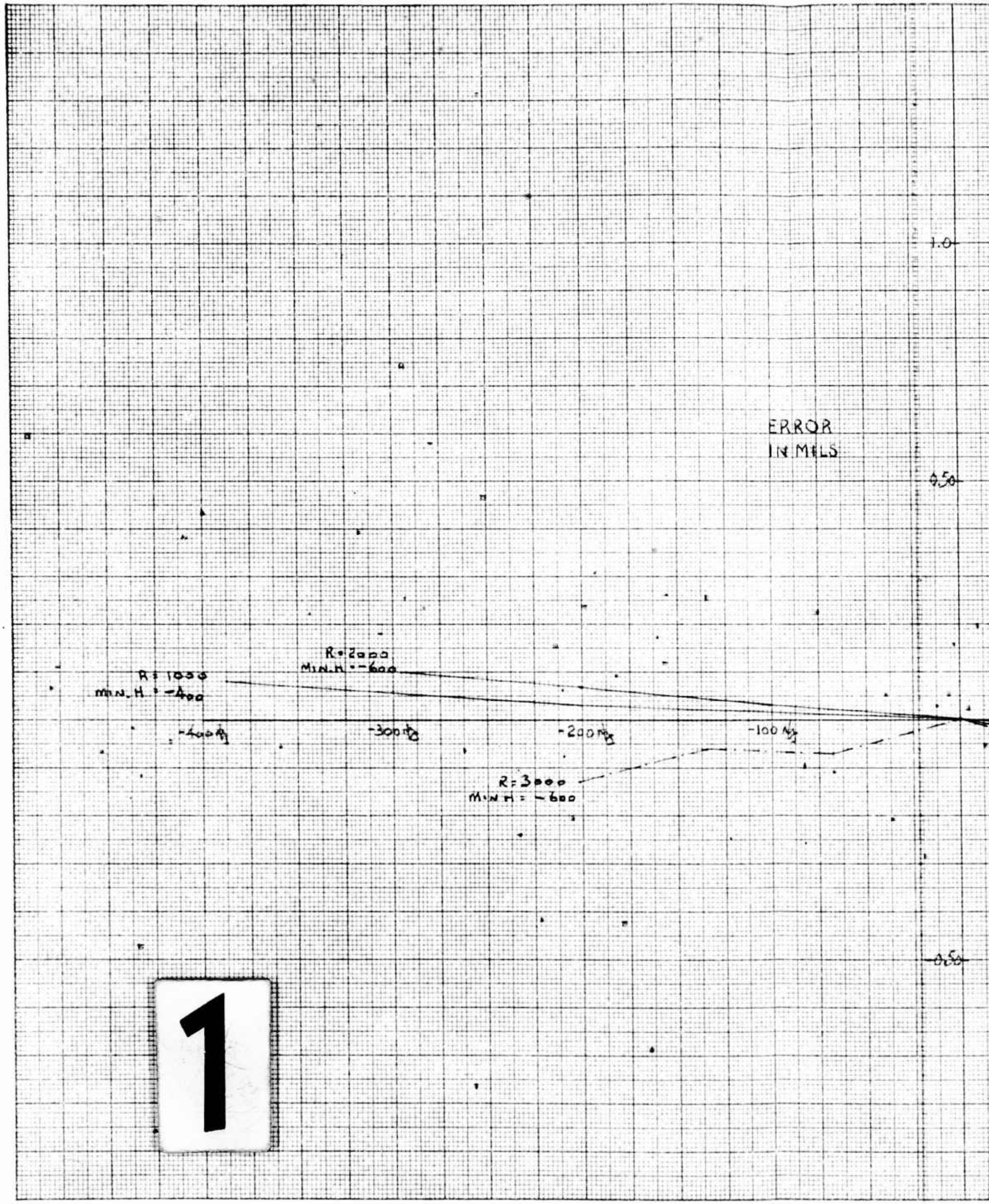


FIGURE 1

KEUFFEL & ESSER Co NEW YORK



10 X 10 TO THE CM. 359T-14L
KEUFFEL & ESSER CO. ALBANENE

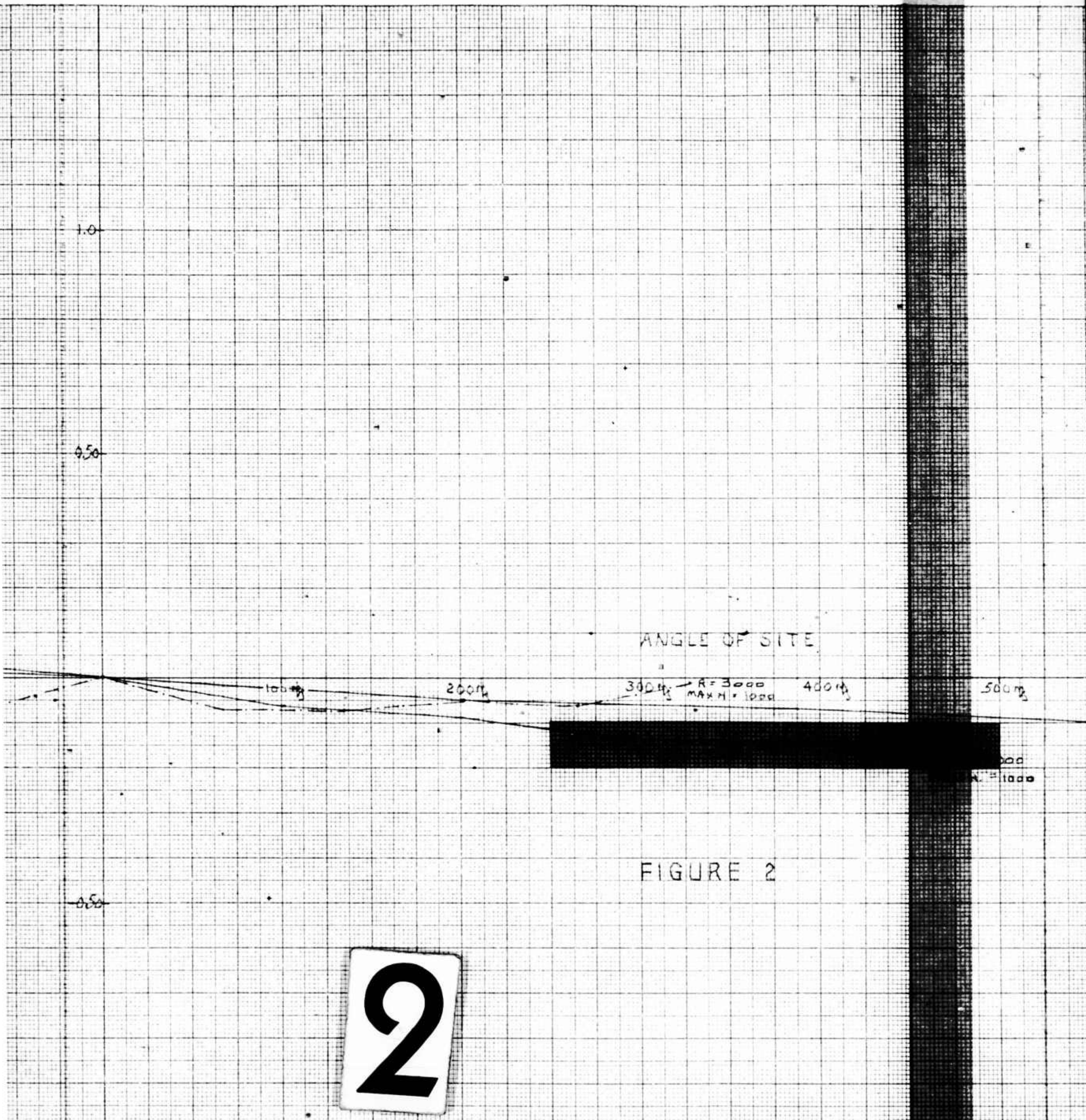

1.0
0.50
-0.50
ANGLE OF SITE
100 m/s
200 m/s
300 m/s
R = 3000
MAX H = 1000
400 m/s
500 m/s
[redacted]

FIGURE 2

3

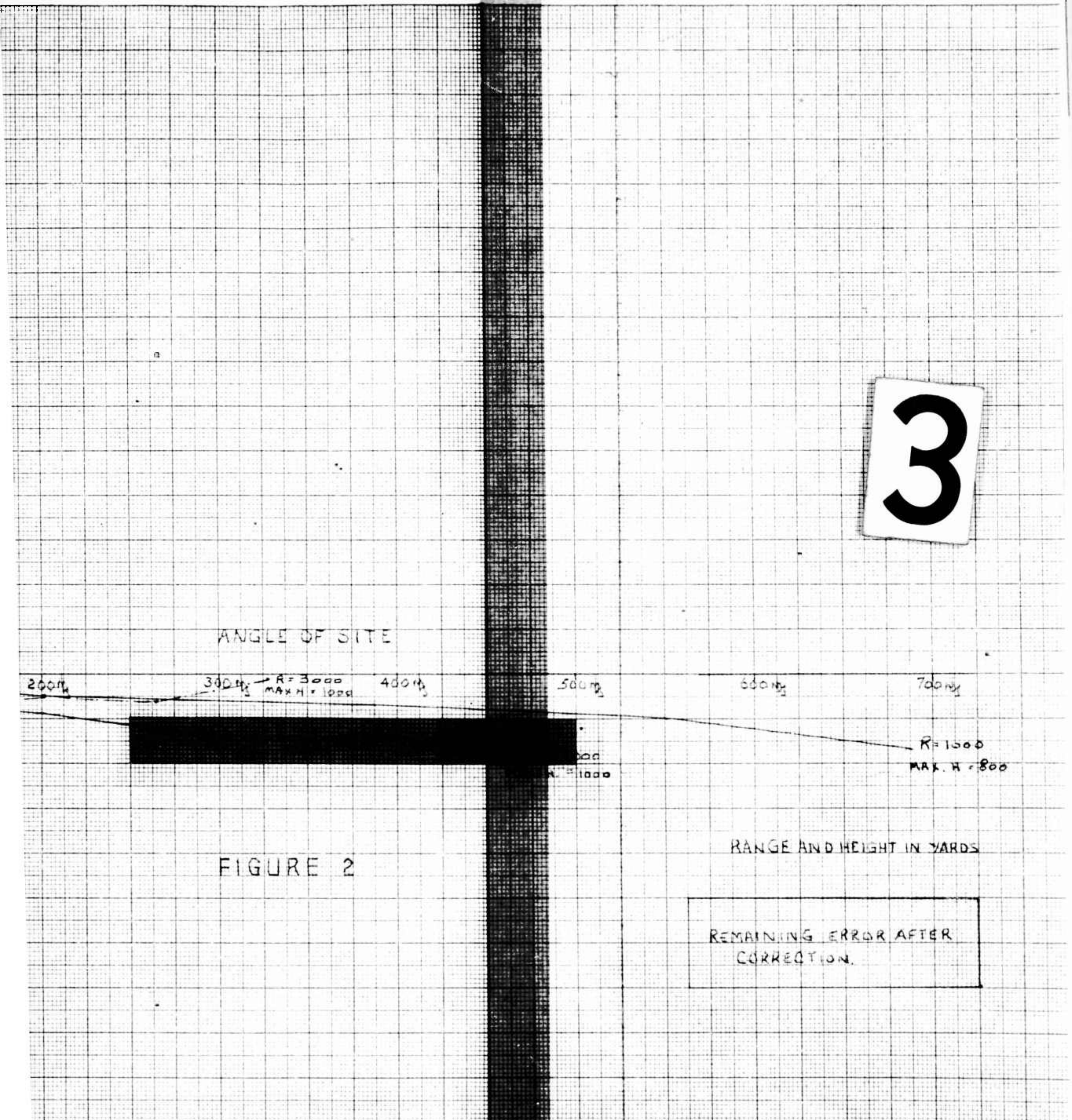

ANGLE OF SITE
200 mils
300 mils
R = 3000
MAX H = 1000
400 mils
500 mils
600 mils
700 mils
[redacted]
R = 1500
MAX. H = 800
RANGE AND HEIGHT IN YARDS
REMAINING ERROR AFTER CORRECTION.

FIGURE 2

BELOCK INSTRUMENT CORPORATION

INTERIM REPORT

ANGLE OF SITE FEASIBILITY STUDY

CONTRACT NO.	SALES ORDER
DA-30-069-ORD-3114	14434

JANUARY 1961

Approved by: [illegible]

Checked by: Lewis Dick

Prepared by: J. Penatzer

INTRODUCTION

Ballistic Computer XM16 has been designed to calculate superelevation for targets located at the same altitude reference as the tank. The computer is provided with data representing slant range to a target, and, through the mechanization of the zero height of target relationships between superelevation and range, calculates the appropriate superelevation. Incidental to this investigation, it should be noted that the computer does correct for many exterior ballistic effects such as cant, drift, gun droop, jump, and wear of the gun tube. Since the only mechanized factors are those pertaining to zero height of target, the computer does not recognize those situations in which the target and tank are at different altitude references.

At present, therefore, the method used to arrive at the desired firing angle is to treat the situation as if the target were at the same height as the tank. The rangefinder is used to determine slant range to the target by elevating it by the angle-of-site. The periscope is used to determine angle of site by sighting on target. As the periscope is elevated (for positive differences between target and tank) the gun is simultaneously elevated through hydraulic power drives. At such time as the computer is energized, the periscope and range finder are automatically depressed by the ballistic drive shaft an amount equivalent to the firing table value of superelevation. Subsequently, the operator in conjunction with the Cadillac gauge superelevation, returns the periscope to the line of site. In doing this, the gun is raised by the amount of superelevation.

Final position of the gun tube is, therefore, angle of site plus firing table superelevation. This procedure outlined above results in certain discreet errors since the assumption is made that the trajectory is rigid and, therefore, does not take into account the required changes in the trajectory due to the angle of site. The purpose of this investigation is to determine the extent of these errors for one of the important future ammunitions to be used with the 105mm gun tube in the M60 tank and a typical ammunition used with the 90mm gun tube in the M48 tank. In addition a recommended method for reducing these errors will be made if the error is significant. The ammunitions considered are the APDS -T,392 for the 105mm gun tube and the HEAT-T-300 (E54) for the 90mm gun tube.

INITIAL INVESTIGATION

The initial investigation into the extent of errors caused by the nonrigidity of the trajectory was accomplished by examining results obtained with the present method of instrumentation and comparing them with computed did-hit values of gun elevation for various ranges of the parameters range and height. Values of gun elevation for ranges of 1000, 2000, 3000, and 4000 yards and for height variations of -700 to at least 1000 yards as determined for the HEAT ammunition are shown in table 2. In the case of the APDS ammunition, the values of complementary angle of site were found. Complementary angle of site is that angle which corrects for the nonrigidity of the trajectory. Table 1 presents these values for the APDS ammunition, and from this it is evident that the errors encountered within the band of interest are small enough to be neglected.

Errors encountered with the HEAT ammunition as indicated in table 5 and figure 1 are sufficiently large to warrant a detailed investigation into methods of error reduction.

DETAILED INVESTIGATION

The premise, that a practical method for correcting the error due to angle of site is necessary, eliminates the possibility of mechanizing the error as a function of range and height. It is evident that instrumentation of the error as a function of range and height would in essence involve the mechanization of the entire ballistic surface of interest.

The investigation of a possible method of correcting for angle of site was conducted with the premise that a practical and easily adaptable solution is required. By analysis of superelevation at its extreme values, it can be seen that for a target located at zero height the angle of site is zero and the superelevation as provided by the computer is correct. At the other extreme, that is for a target located ninety degrees from the horizontal, the angle of site is ninety degrees and any deviation from this angle would result in error. This analysis of total gun elevation in its extreme positions led to the initial approximation of total gun elevation to be Eo Cos (S)+S, where Eo is zero height elevation associated with slant range and S is angle of site. This function is seen to be correct in the extreme cases as described above, since Cos S is zero when angle of site is ninety degrees and unity when angle of site is zero. The effectiveness of this function as a correction factor was noticeable but the error remaining was still significant.

It was next found that by using the expression Eo Cos $(E_o+S)+S$ we could more closely approximate the function for total elevation. Comparing the values of this function (table 6) with the values for true total elevation (table 2) resulted in errors remaining as indicated in table 7 and figure 2. As can be seen, the errors were still significant in cases where range and height parameters were large.

We next assumed that there exists a factor K such that $E = E_o \cos (E_o+S+K)$. This quantity was evaluated $(K = \cos^{-1} (\frac{E}{E_o}) - E_o-S)$ and although not a constant, it was found that by the insertion of a value of $K = 3°$ into the cosine formula, we could further reduce the error remaining to a point well within the realm of error of the computer. The values for $E = E_o \cos (E_o + S + K)$ can be seen in table 8 and comparison of these values with the "did-hit" values of table 2 indicated errors still remaining as shown in table 9 and figure 3. Figure 4 is an expanded version of figure 3 in which remaining errors may be more closely examined.

It should be noted finally that for the primary area of interest (i.e., ranges of 500 to 3000 yards and heights of -400 to 1000 yards) the maximum error remaining after correction is 0.2 mils as compared to an error of over 2.0 mils without correction. It is recommended, therefore, that the function $E_o \cos (E_o+S+3°)$ be instrumented as a method of correction. Further study should be made to investigate the optimum corrective equation for the various tank ammos.

CONCLUSION

At present the best possible and most practical method of mechanizing a function similar to the above is being studied.

INDEX OF TABLES

MATH DATA SHEET

Table 1

Height	Range 1000	Range 2000	Range 3000	Range 4000
-500	-0.1	-0.1	0	-0.1
0	0	0	0	0
500	0.1	0.1	0	0.1
1000		0.1	0.1	0.1
1500			0.1	0.1
2000				0.2

MATH DATA SHEET

Table 2

Height	Range 1000	Range 2000	Range 3000	Range 4000
-700	-617.92	-331.90	-209.01	-121.70
-600	-546.39	-285.97	-176.90	- 97.58
-500	-468.27	-238.74	-144.32	- 73.20
-400	-383.63	-190.37	-111.35	- 48.62
-300	-292.96	-141.04	- 78.05	- 23.80
-200	-197.18	- 90.96	- 44.49	1.19
-100	- 97.65	- 40.36	- 10.74	26.31
0	3.87	10.51	23.11	51.54
100	105.39	61.39	57.02	76.84
200	204.95	112.04	90.88	102.17
300	300.78	162.20	124.62	127.51
400	391.52	211.66	158.17	152.83
500	476.25	260.19	191.47	178.09
600	554.52	307.61	224.44	203.27
700	626.21	353.76	257.03	228.33
800	691.49	398.52	289.17	253.26
900	750.72	441.78	320.83	278.02
1000	804.35	483.48	351.95	302.59
1100		523.56	382.50	326.96
1200.		562.02	412.44	351.10
1300		598.84	441.75	375.00
1400			470.40	398.63
1500			498.39	421.98
1600			525.69	445.05
1700			552.30	467.83
1800			578.22	490.30
1900			603.46	512.48
2000			628.02	534.35
2100			651.91	555.91
2200			675.15	577.16
2300				598.10

BELOCK INSTRUMENT CORP. FORM MD80356

MATH DATA SHEET

Table 3

Height	Range 1000	Range 2000	Range 3000	Range 4000
-700	5.11	11.59	24.63	54.14
-600	4.79	11.30	24.22	53.46
-500	4.49	11.07	23.88	52.86
-400	4.26	10.87	23.62	52.39
-300	4.09	10.71	23.39	52.01
-200	3.96	10.60	23.24	51.75
-100	3.89	10.54	23.15	51.58
0	3.86	10.51	23.11	51.54
100	3.89	10.54	23.15	51.58
200	3.96	10.60	23.24	51.75
300	4.09	10.71	23.39	52.01
400	4.26	10.87	23.62	52.39
500	4.49	11.07	23.88	52.86
600	4.79	11.30	24.22	53.46
700	5.11	11.59	24.63	54.14
800	5.42	11.95	25.07	54.91
900	5.80	12.34	25.66	55.80
1000	6.24	12.77	26.28	56.86
1100		13.24	26.97	58.01
1200		13.76	27.78	59.30
1300		14.35	28.67	60.69
1400			29.62	62.21
1500			30.69	63.93
1600			33.02	65.72
1700			33.26	67.74
1800			34.80	69.86
1900			36.24	72.17
2000			37.66	74.83
2100			39.44	77.30
2200			41.31	80.17
2300				83.21

BELOCK INSTRUMENT CORP. FORM MD80356

MATH DATA SHEET

Table 4

Height	Range 1000	Range 2000	Range 3000	Range 4000
-700	-616.97	-331.35	-208.86	-122.32
-600	-545.67	-285.58	-176.85	- 98.20
-500	-467.88	-238.46	-144.33	- 73.81
-400	-383.33	-190.20	-111.37	- 49.13
-300	-292.79	-140.95	- 78.13	- 24.24
-200	-197.11	- 90.92	- 44.56	0.86
-100	- 97.63	- 40.35	- 10.79	26.12
0	3.86	10.51	23.11	51.54
100	105.41	61.43	57.09	77.04
200	205.03	112.12	91.04	102.64
300	300.97	162.37	124.91	128.26
400	391.85	211.94	158.61	153.91
500	476.76	260.60	192.09	179.53
600	555.25	308.18	225.29	205.12
700	627.19	354.53	258.12	230.60
800	692.71	399.54	290.52	255.98
900	752.24	443.04	322.54	281.21
1000	806.24	485.04	354.01	306.39
1100		525.44	384.95	331.37
1200		564.22	415.37	356.18
1300		601.45	445.17	380.77
1400			474.37	405.15
1500			502.96	429.37
1600			532.08	453.37
1700			558.43	477.12
1800			585.26	500.56
1900			611.29	523.87
2000			636.60	547.10
2100			661.52	569.73
2200			685.80	592.37
2300				614.74

MATH DATA SHEET

Table 5

Height	Range 1000	Range 2000	Range 3000	Range 4000
-700	+0.95	+0.55	+0.15	-0.62
-600	+0.72	+0.39	+0.05	-0.62
-500	+0.39	+0.28	-0.01	-0.61
-400	+0.30	+0.17	-0.02	-0.51
-300	+0.17	+0.09	-0.08	-0.44
-200	+0.08	+0.04	-0.07	-0.33
-100	+0.02	+0.01	-0.05	-0.19
0	-0.01	0.00	0.00	0.00
100	0.02	0.04	0.07	0.20
200	0.08	0.08	0.16	0.47
300	0.19	0.17	0.29	0.75
400	0.33	0.28	0.44	1.08
500	0.51	0.41	0.62	1.44
600	0.73	0.57	0.85	1.85
700	0.98	0.77	1.09	2.27
800	1.22	1.02	1.35	2.72
900	1.52	1.26	1.71	3.19
1000	1.89	1.56	2.06	3.80
1100		1.88	2.45	4.41
1200		2.20	2.93	5.08
1300		2.61	3.42	5.77
1400			3.97	6.52
1500			4.57	7.39
1600			6.39	8.26
1700			6.13	9.29
1800			7.04	10.26
1900			7.83	11.39
2000			8.58	12.75
2100			9.61	13.82
2200			10.65	15.21
2300				16.64

BELOCK INSTRUMENT CORP. FORM MD50356

MATH DATA SHEET

Table 6

Height	Range 1000	Range 2000	Range 3000	Range 4000
-700	-617.88	-331.96	-209.38	-122.71
-600	-546.34	-286.02	-177.21	- 98.45
-500	-468.35	-238.76	-144.57	- 73.95
-400	-383.63	-190.39	-111.51	- 49.19
-300	-292.96	-141.05	- 78.20	- 24.25
-200	-197.18	- 90.96	- 44.58	0.86
-100	- 97.65	- 40.36	- 10.79	26.10
0	3.86	10.51	23.10	51.47
100	105.39	61.41	57.05	76.89
200	204.95	112.06	90.95	102.38
300	300.79	162.23	124.73	127.85
400	391.54	211.71	158.32	153.30
500	476.28	260.24	191.67	178.71
600	554.56	307.67	224.70	204.04
700	626.25	353.84	257.33	229.22
800	691.51	398.63	289.51	254.25
900	750.73	441.89	321.26	279.12
1000	804.39	483.62	352.44	303.84
1100		523.72	383.05	328.33
1200		562.16	413.09	352.59
1300		599.02	442.48	376.58
1400			471.22	400.29
1500			499.29	423.77
1600			527.68	446.91
1700			553.56	469.83
1800			579.67	492.29
1900			604.98	514.53
2000			629.48	536.56
2100			653.49	557.95
2200			676.79	579.19
2300				600.04

BELOCK INSTRUMENT CORP. FORM MDS0356

Table 7.

Height	Range 1000	Range 2000	Range 3000	Range 4000
-700	-0.04	-0.06	-0.37	-1.01
-600	-0.05	-0.05	-0.31	-0.87
-500	-0.08	-0.02	-0.25	-0.75
-400	0.00	-0.02	-0.16	-0.57
-300	0.00	-0.01	-0.15	-0.45
-200	0.00	0.00	-0.09	-0.33
-100	0.00	0.00	-0.05	-0.21
0	0.00	0.00	-0.01	-0.07
100	0.00	0.02	0.03	0.05
200	0.00	0.02	0.07	0.21
300	0.01	0.03	0.11	0.34
400	0.02	0.05	0.15	0.47
500	0.03	0.05	0.20	0.62
600	0.04	0.06	0.26	0.77
700	0.04	0.08	0.30	0.89
800	0.03	0.11	0.34	0.99
900	0.01	0.11	0.43	1.10
1000	0.04	0.14	0.49	1.25
1100		0.16	0.55	1.37
1200		0.14	0.65	1.49
1300		0.18	0.73	1.58
1400			0.82	1.66
1500			0.90	1.79
1600			1.09	1.86
1700			1.26	2.00
1800			1.45	1.99
1900			1.52	2.05
2000			1.46	2.21
2100			1.58	2.04
2200			1.64	2.03
2300				1.94

Table 8

Height	Range 1000	Range 2000	Range 3000	Range 4000		
-700	-617.73	-331.78	-208.90	-122.04		
-600	-546.22	-285.87	-177.03	- 98.25		
-400	-383.55	-190.30	-111.41	- 49.13		
-200	-197.15	- 90.93	- 44.56	0.79		
0	3.85	10.49	23.05	51.27		
200	204.90	111.98	90.81	102.03		
400	391.45	211.57	158.10	152.83		
600	554.42	307.47	224.39	203.41		
800	691.32	398.38	289.11	253.47		
1000	804.15	483.30	351.94	302:88		
1200		561.77	412.48	351.45		
1400			470.48	398.95		
1600			526.77	445.34		
1800			578.64	490.48		
2000			628.28	534.48		
2200			675.39	576.79		
2300				597.47		

MATH DATA SHEET

Table 9

Height	Range 1000	Range 2000	Range 3000	Range 4000
-700	.19	.12	.11	-.74
-600	.17	.10	-.13	-.67
-400	.08	.07	-.06	-.51
-200	.03	.03	-.07	-.40
0	-.02	-.02	-.06	-.27
200	-.05	-.06	-.07	-.14
400	-.07	-.09	-.07	0
600	-.10	-.14	-.05	.14
800	-.17	-.14	-.06	.21
1000	-.20	-.18	-.01	.29
1200		-.25	.04	.35
1400			.08	.32
1600			.08	.29
1800			.42	.18
2000			.26	.13
2200			.24	-.37
2300				-.63

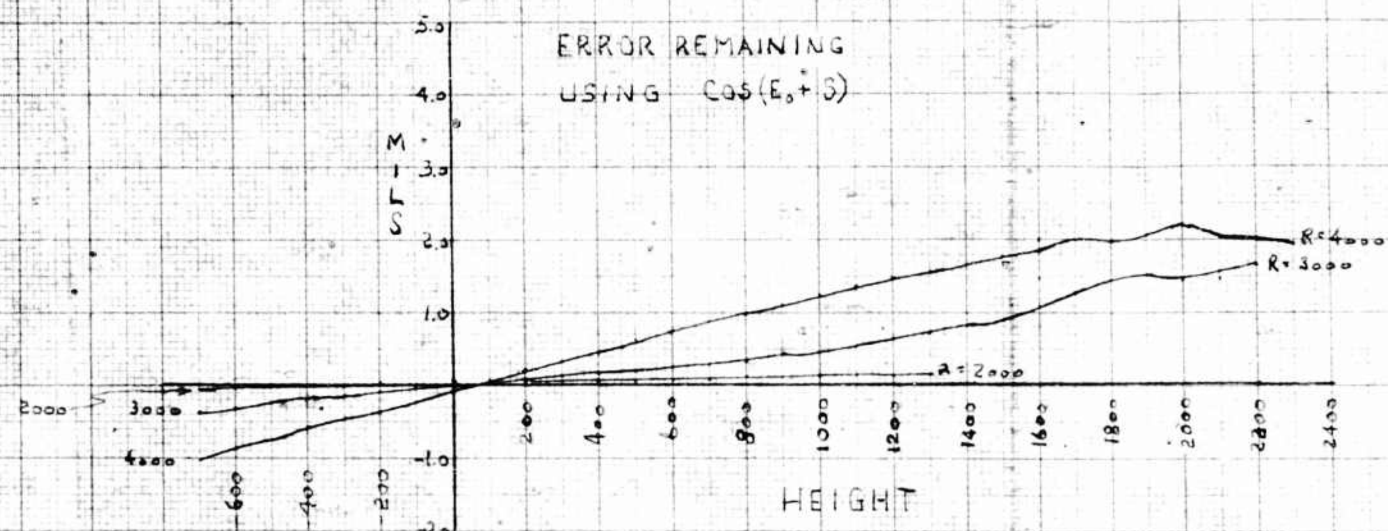
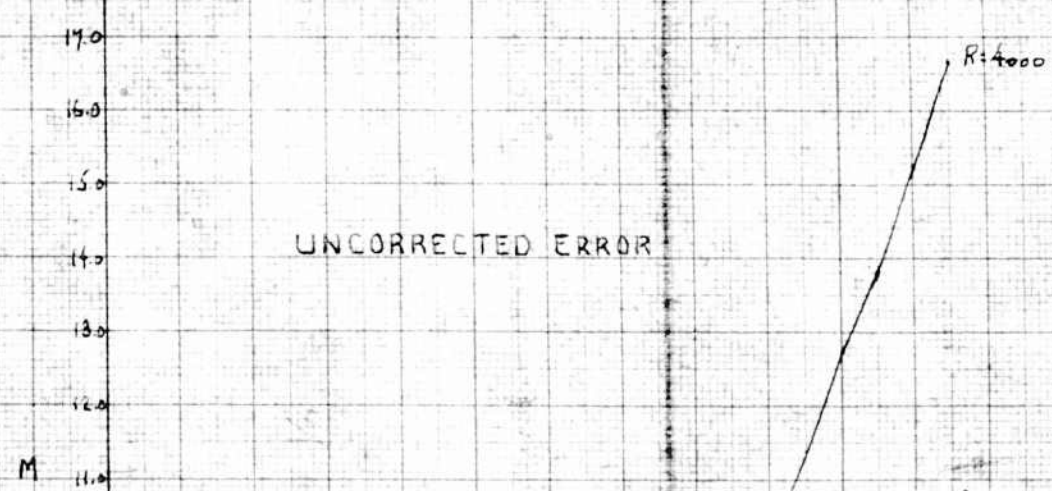
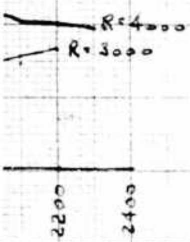
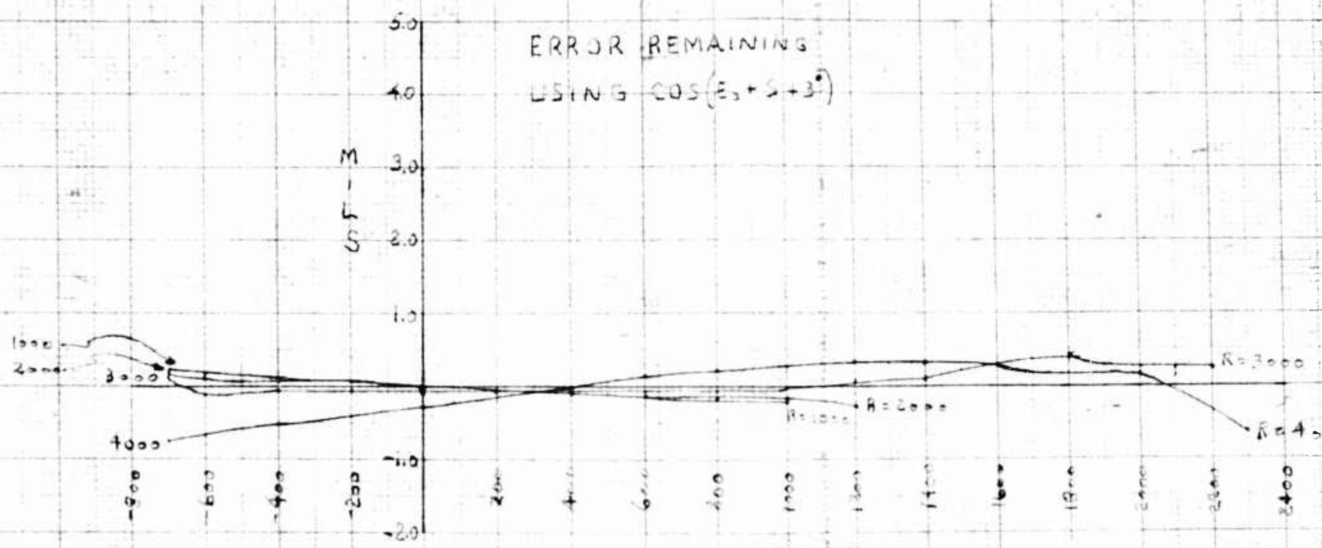


FIGURE #2

CURVE FOR R=1000 YDS RANGE IS REPRESENTED BY ABCISSA.



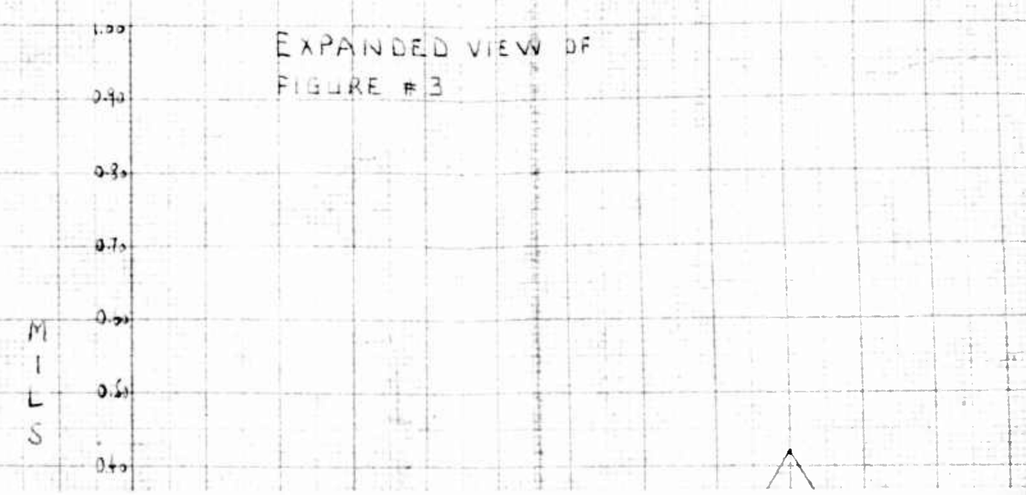




...o yds RANGE IS
...y ABSCISSA.

FIGURE #3

2



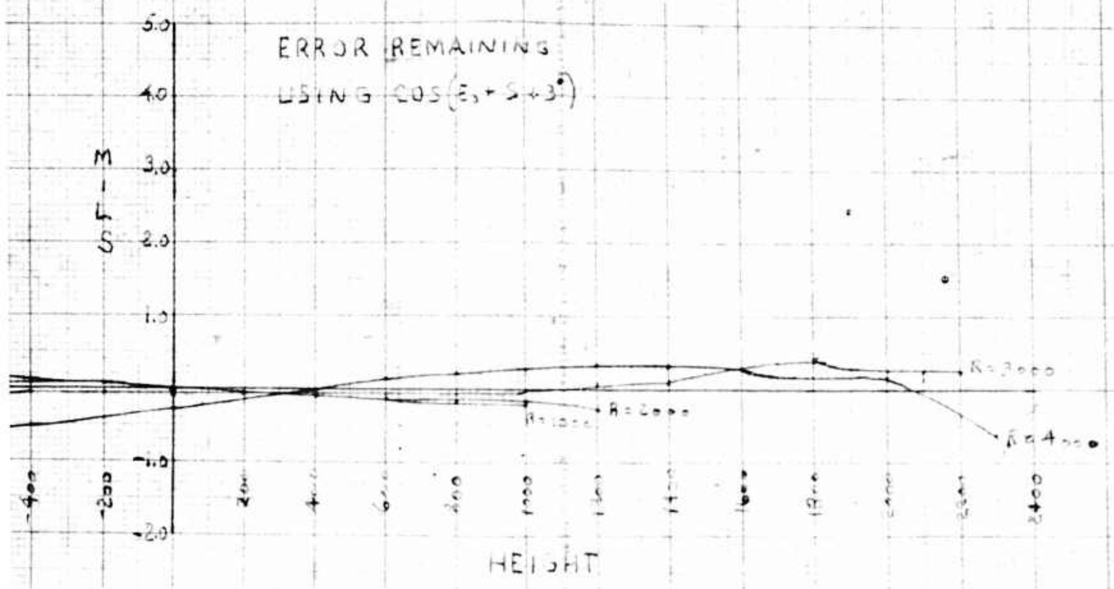
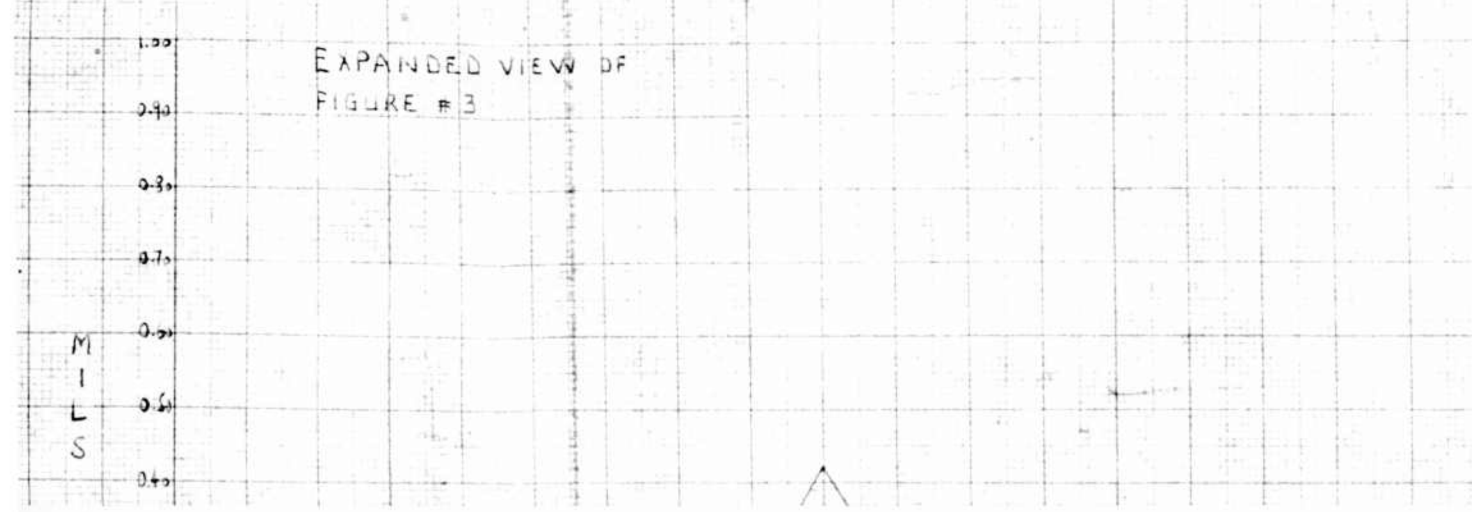
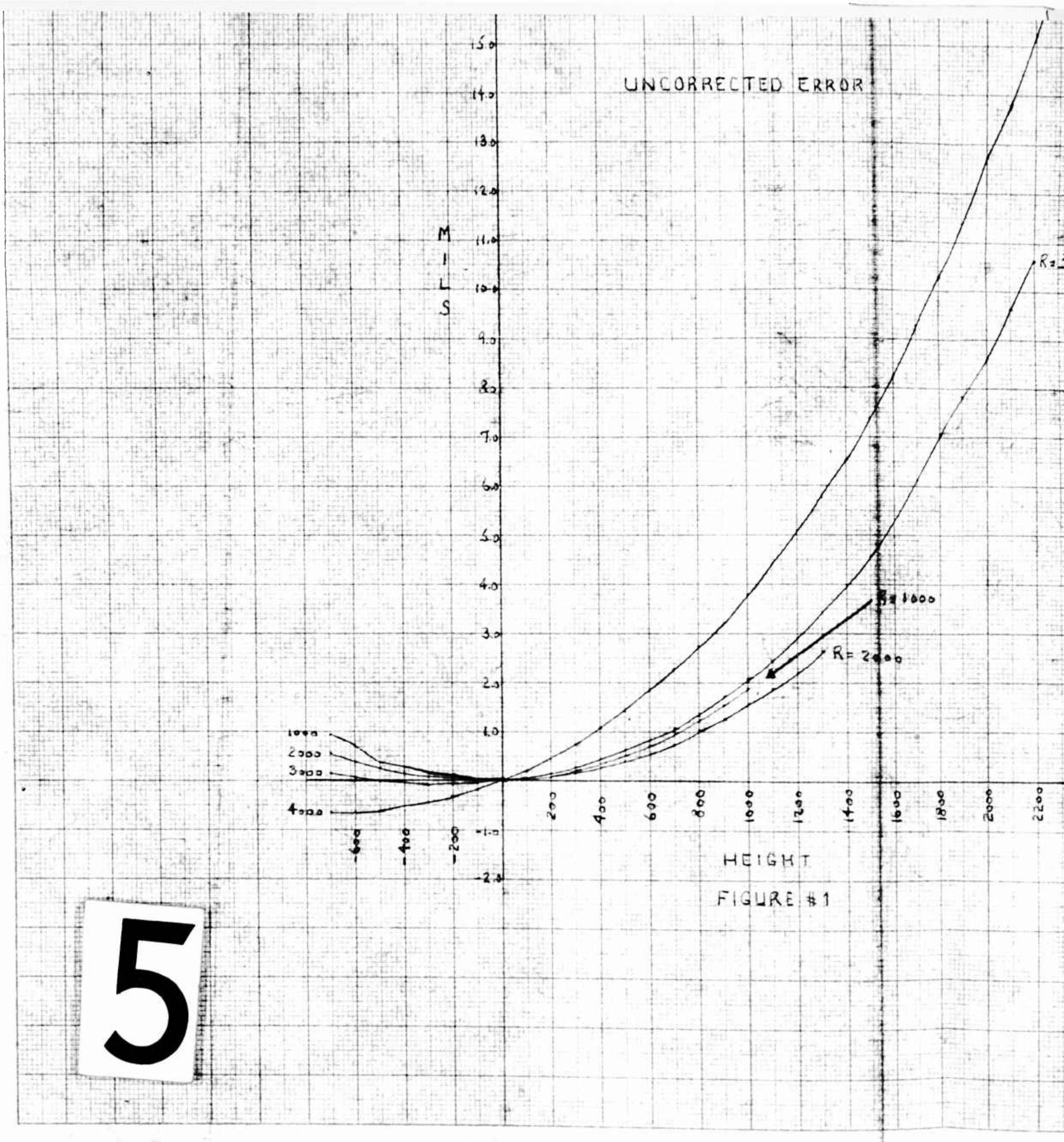

ERROR REMAINING
USING COS(E, + S + 3°)
MILS
5.0
4.0
3.0
2.0
1.0
-1.0
-2.0
R=3000
R=2000
R=1000
R=4000
-400
-200
2400
HEIGHT

FIGURE #3

3


EXPANDED VIEW OF
FIGURE #3
MILS



UNCORRECTED ERROR
M I L S
HEIGHT
R=3
R=1000
R= 2000
1000
2000
3000
4000

FIGURE #1

5

FIGURE #4

6

ANGLE-OF-SIT
STUDY FOR X
14434

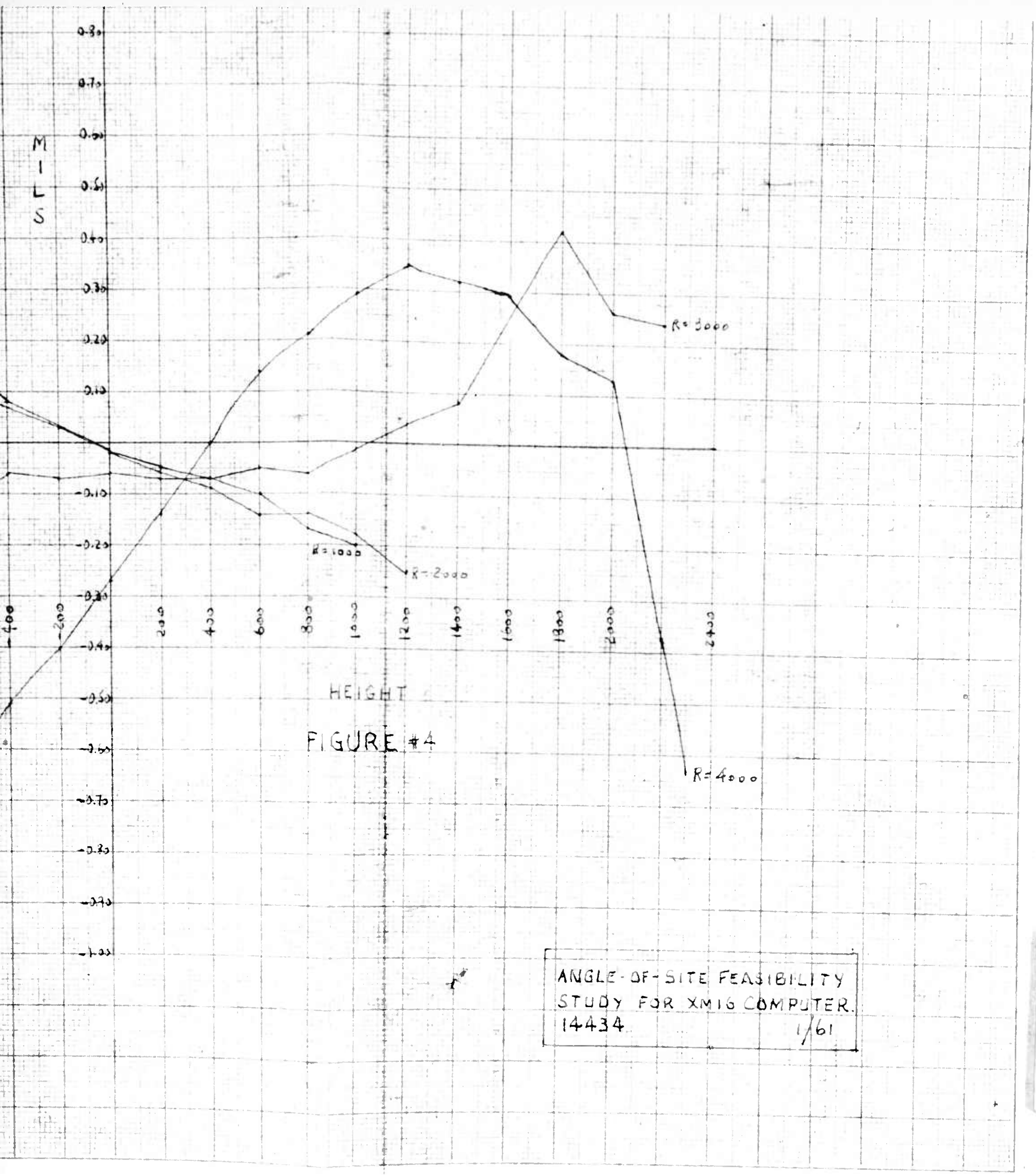


FIGURE #4

ANGLE-OF-SITE FEASIBILITY STUDY FOR XM16 COMPUTER.
14434 1/61

7

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